Near-Infrared Synthetic Spectra of Elliptical Galaxies

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Abstract: We present near-infrared (0.7–3 μm) synthetic spectra from our initial population synthesis models of elliptical galaxies. We measure broad-band colors from the spectra and compare the results to the models of Worthey (1994) and to observations of E/S0 galaxies.

arXiv:astro-ph/9611007v1 1 Nov 1996

1. Introduction

In theory, knowledge of the present-day stellar populations of a galaxy can be used to derive the star formation history of that galaxy. In practice, however, decomposing the integrated light of a galaxy to determine the characteristics of its various stellar populations is a daunting task. Even in a simple stellar population (SSP), *i.e.* a coeval group of stars having a common chemical composition, the effects of age and metallicity variations on the integrated light can be quite degenerate (see Worthey 1994; hereafter W94).

One analytical method which is a potentially powerful tool in integrated light studies is population synthesis. With this application in mind, we have used synthetic stellar spectra to construct integrated spectra of elliptical galaxies. We present here our initial near-infrared (0.7–3 μm) synthetic spectra of E galaxies, examine how these spectra are affected by changes in age and metallicity and compare our results to the models of W94. This research builds upon the previous work of Tripicco & Bell (1995), Houdashelt & Bell (1996), Bell & Briley (1991) and Houdashelt (1995). A companion paper in this volume presents a complementary discussion of our optical synthetic spectra (3000–7000 Å).

2. Some Details of the Models

In this initial set of models, elliptical galaxies were represented by SSPs. In this way, the effective temperature, surface gravity distribution of the stars in a galaxy could be described by a single isochrone. We used Dorman (1996, private communication) isochrones through the tip of the first-ascent red giant branch (RGB) and Sweigart (1996, private communication) horizontal-branch and asymptotic-giant-branch tracks thereafter. A Salpeter (1955) IMF was assumed in each case. The nine synthetic spectra discussed here represent 6, 10 and 16 Gyr SSPs having [Fe/H]=+0.39, 0.00 and –0.47.

Updated MARCS stellar atmosphere models (Gustafsson *et al.* 1975) were calculated for a representative sample of stars along each isochrone, and synthetic spectra were then computed using the SSG spectral synthesis code (Bell

& Gustafsson 1978, 1989; Gustafsson & Bell 1979). In computing the synthetic spectra, the microturbulent velocity, v_t, was varied linearly with log g, such that (1) v_t=1.0 km sec^{-1} for log $g \geq 4.5$, (2) v_t=2.5 km sec^{-1} for log $g \leq 0.5$, and (3) v_t=1.7 km sec^{-1} for log g=1.7. Solar abundance ratios were used in all but two instances. For consistency with the isochrones, the [Fe/H]=–0.47 models also had [O/Fe]=+0.23. In addition, following observational determinations, all stars which were more evolved than the RGB bump were assumed to have mixed CNO-processed material into their stellar atmospheres, such that [C/H]=–0.19, [N/H]=+0.28, [O/H]=–0.04, and ^{12}C/^{13}C=14 (Smith & Lambert 1990).

3.   Results

Figure 1 illustrates the near-infrared synthetic spectrum of our 16 Gyr, solar-metallicity elliptical galaxy. The *JHK* filter profiles of Bessell & Brett (1988) and the filter profiles of the CIT/CTIO CO index (Cohen *et al.* 1978) are also plotted. The well-known Δv=3 and Δv=2 CO bands with bandheads near 1.5 and 2.3 μm, respectively, are easily discerned in the synthetic spectrum and are obviously the dominant features in the *H* and *K* bands. Most of the strong absorption bands shortward of 1.5 μm are due to TiO; the ϕ band of TiO is especially important between $\sim$0.9 and 1.5 μm and has a significant impact on the *J*-band flux. The Ca II triplet near 8500 Å is evident in Figure 1 as well. Since we are not aware of any medium- or high-resolution spectra of E/S0 galaxies between 1 and 3 μm, the spectrum shown in Figure 1 can serve as a guide to observers until such data exists.
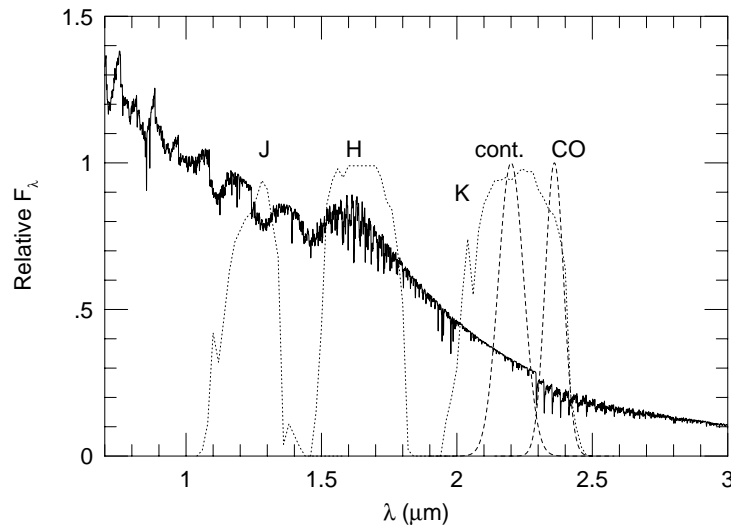
Figure 1. Our near-infrared synthetic spectrum for a 16 Gyr, [Fe/H]=0.0 stellar population (solid line). The dotted lines are the *J*, *H* and *K* filter profiles on the Bessell & Brett (1988) Johnson-Glass system. The dashed lines are the filter profiles used to measure the CIT/CTIO CO index (Cohen *et al.* 1978).

To evaluate our models, we measured integrated colors from the synthetic spectra. Figure 2 compares our near-infrared colors to observations of early-type galaxies and to the model predictions of W94; all of the photometry has been put on the Johnson-Glass system of Bessell & Brett (1988).
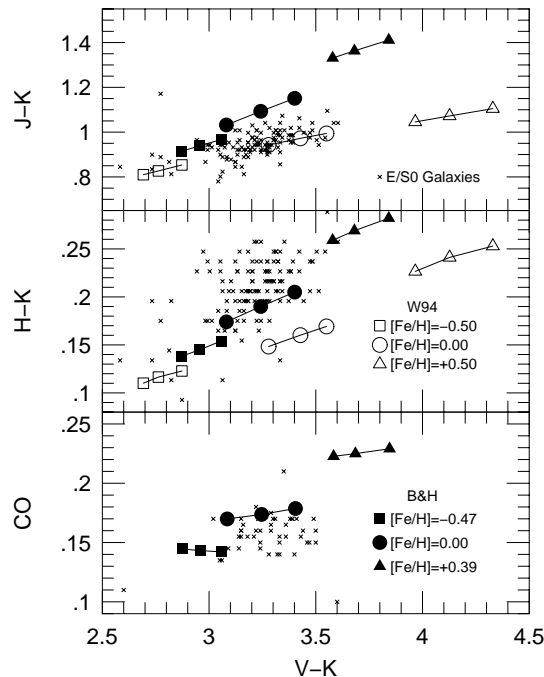
Figure 2. The near-infrared colors measured from our spectral synthesis models are compared to the model predictions of W94 and the observed colors of early-type galaxies (Frogel *et al.* 1978, Persson *et al.* 1979). From blue to red, our models represent 6, 10 and 16 Gyr populations; the W94 models shown have ages of 8, 12 and 17 Gyr.

Taken alone, the $V - K$ colors indicate that the reddest ellipticals are most likely old and have approximately solar metallicity. Whether the bluer ellipticals are younger or more metal-poor cannot be determined from the integrated colors, since the age and metallicity vectors are nearly parallel in the color-color plots, as previously known (W94). Since the $V - K$ colors are consistent with the age and metallicity inferred from the $B - V$ colors of our models (see Bell & Houdashelt elsewhere in this volume), we are confident that our synthetic spectra are accurately representing the K-band fluxes of elliptical galaxies.

Silva (1996) has shown that the population synthesis models of W94 and Bruzual & Charlot (1993) cannot reproduce the $J - H$, $H - K$ colors of early-type galaxies. Figure 2 indicates that our present models suffer from similar difficulties but with some differences. While our models reasonably match the E/S0 galaxies in the $H - K$, $V - K$ diagram and the W94 models do not,

the opposite is true for the $J - K$, $V - K$ colors. However, comparisons of our synthetic stellar spectra and spectra of field M giants from Terndrup *et al.* (1991) lead us to believe that we have overestimated the oscillator strengths of the spectral lines in the ϕ system of TiO, which is very prominent in the synthetic spectrum shown in Figure 1. The J-band magnitudes are particularly sensitive to this system of TiO, so TiO bands which are too strong would make our $J - K$ colors too red. We intend to explore this hypothesis more fully in the near future, but for now, a significant discrepancy remains between our model $J - K$ colors and those of early-type galaxies. On the other hand, our model $V - K$, $H - K$ trends are a much better match to the galaxy data, even though the E/S0 galaxies tend to be slightly redder in $H - K$ than our solar-metallicity models.

We have had great success in synthesizing the 2.3 μm CO band in giants (Briley & Bell 1991, Houdashelt & Bell 1996), and our model CO indices span the observational measurements of early-type galaxies. While our models infer that giant ellipticals have slightly subsolar metallicities, we must explore the sensitivity of the CO bands to our treatment of CNO mixing in the giants before drawing any specific conclusions from the CO indices.

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